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(54) Detecting the instant of arrival of a seismic wave

(57) In a seismic measuring method, a plurality of shocks are transmitted from a source (30) at the surface (32) of the ground to cause seismic waves to propagate through the ground to be picked-up by a geophone (20) located down a borehole (11). Traces of the signals received by the geophone are recorded. A magnitude which is a function of the recorded traces is calculated for each instant following the initial shock, and the statistical distribution of said magnitude at each of said instants is examined. A threshold probability is determined, above which said distribution is considered to correspond to the existence of coherence between the different recorded traces for said instant. The recorded traces are examined together in order of increasing time. When, for example, three con-

(57) continued overleaf...

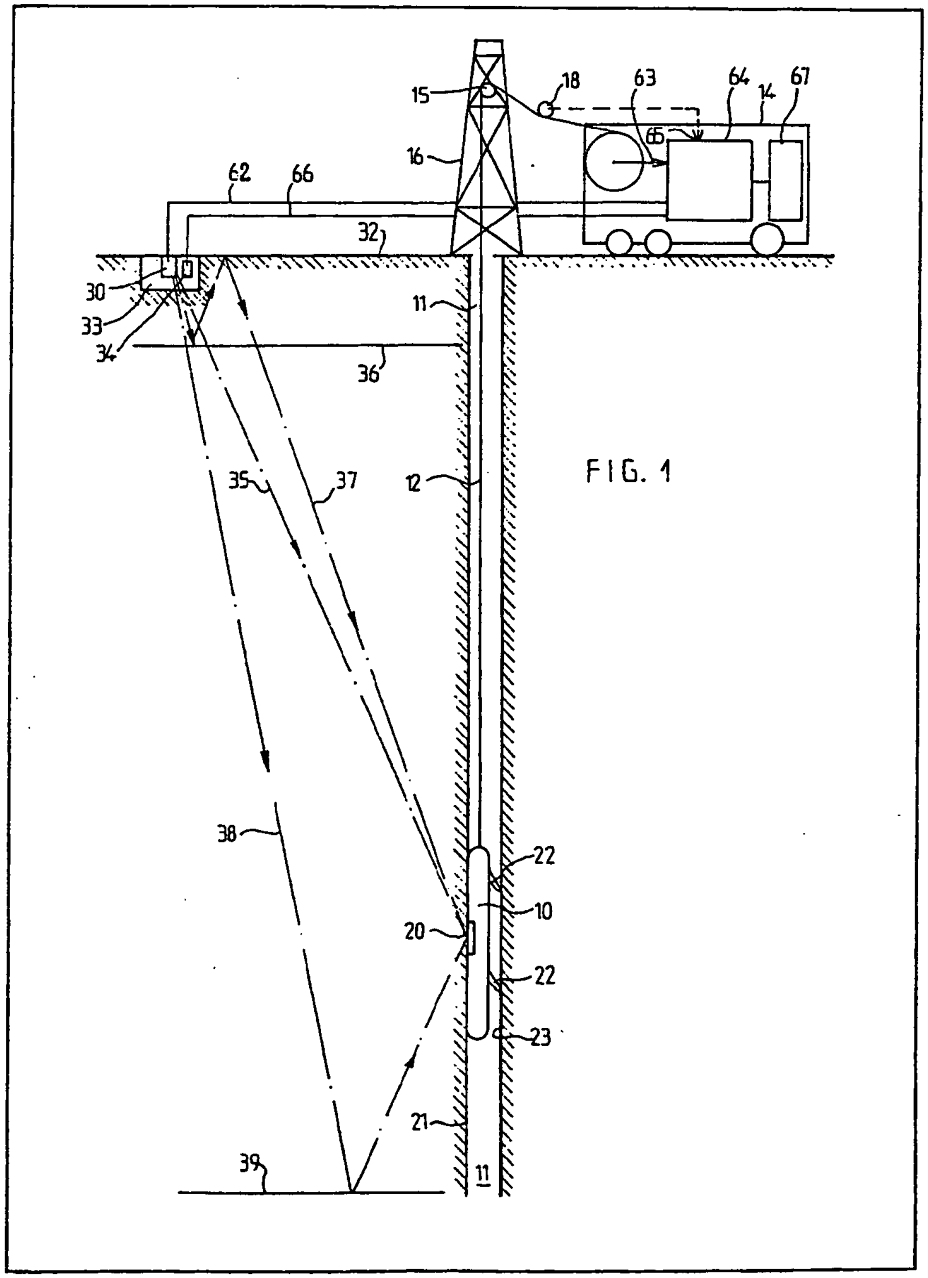

FIG. 1

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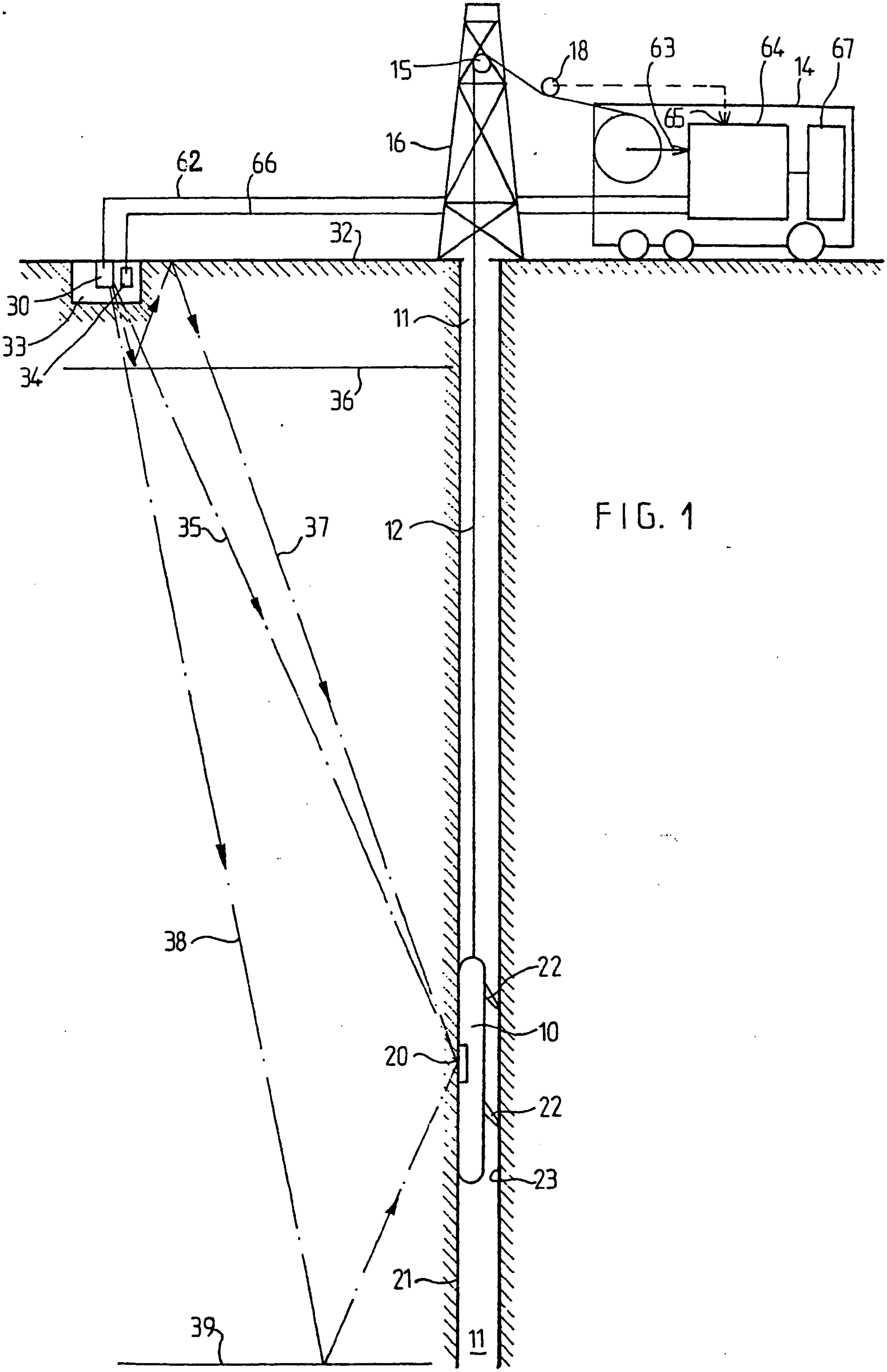
secutive instants all give a distribution above said threshold, it is assumed that the recorded signal corresponds to the first arrival of the shock wave at the geophone, and the instant of first arrival is consequently determined.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11

FIG. 1

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FIG. 2A

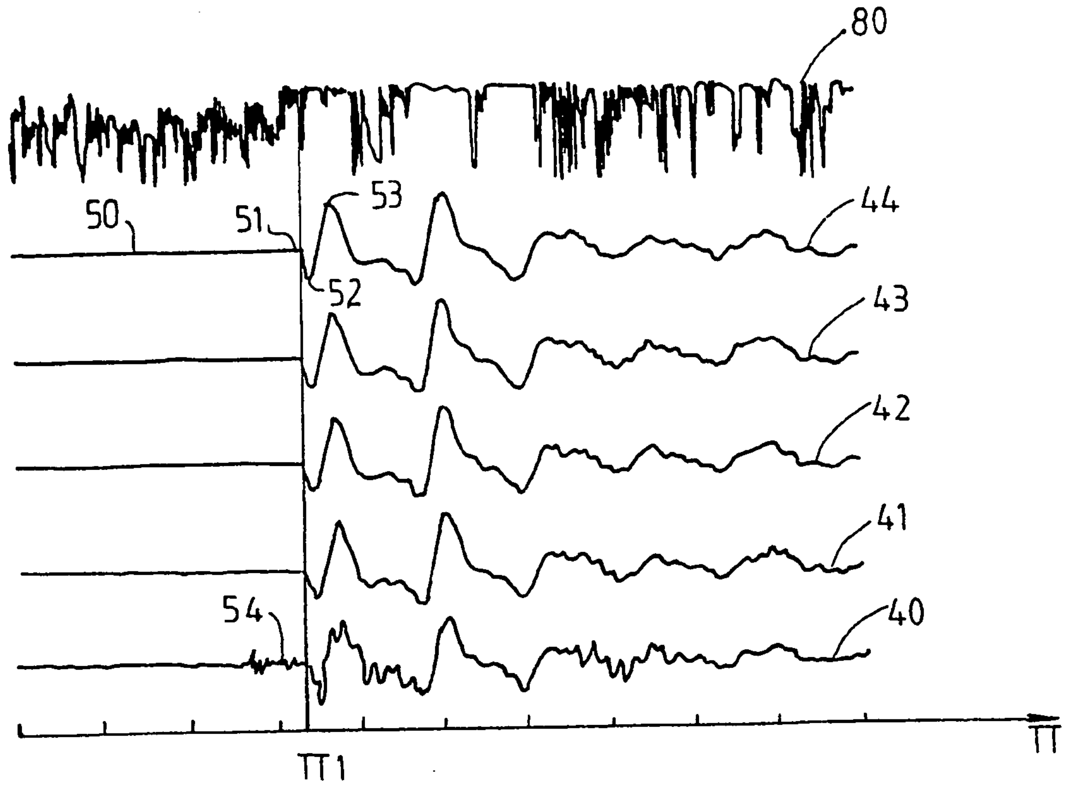


FIG. 2B

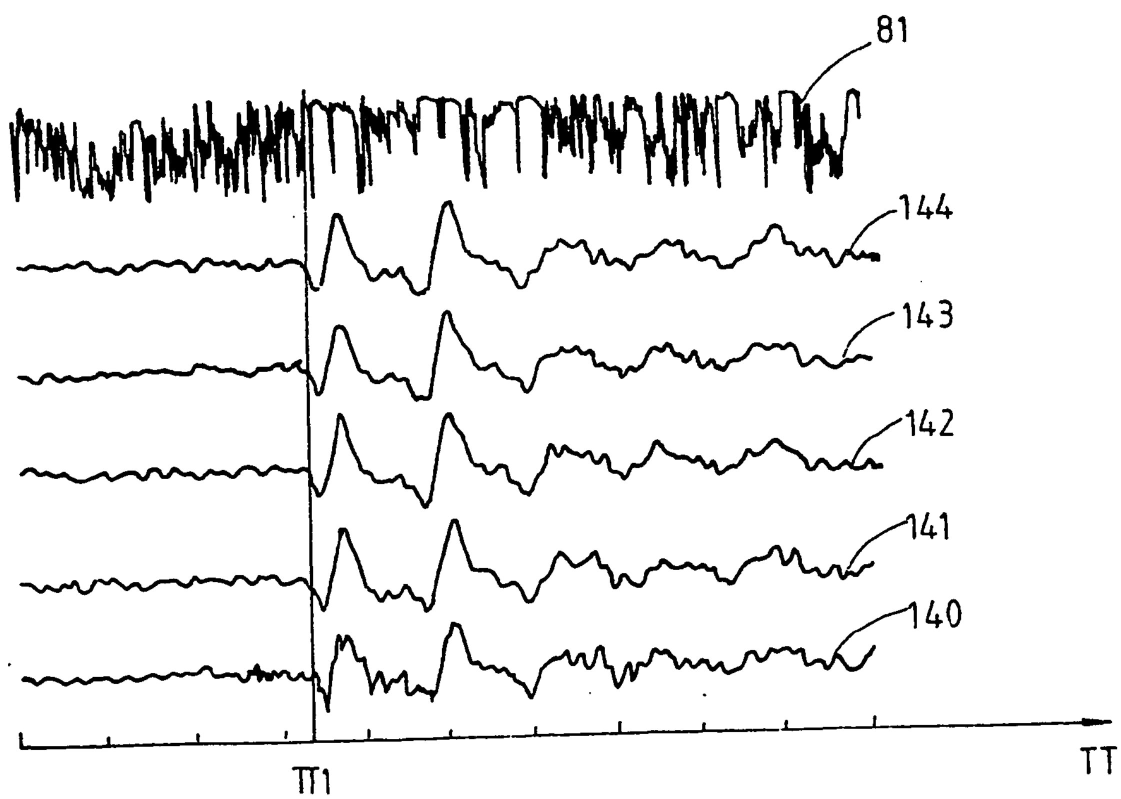


FIG. 3

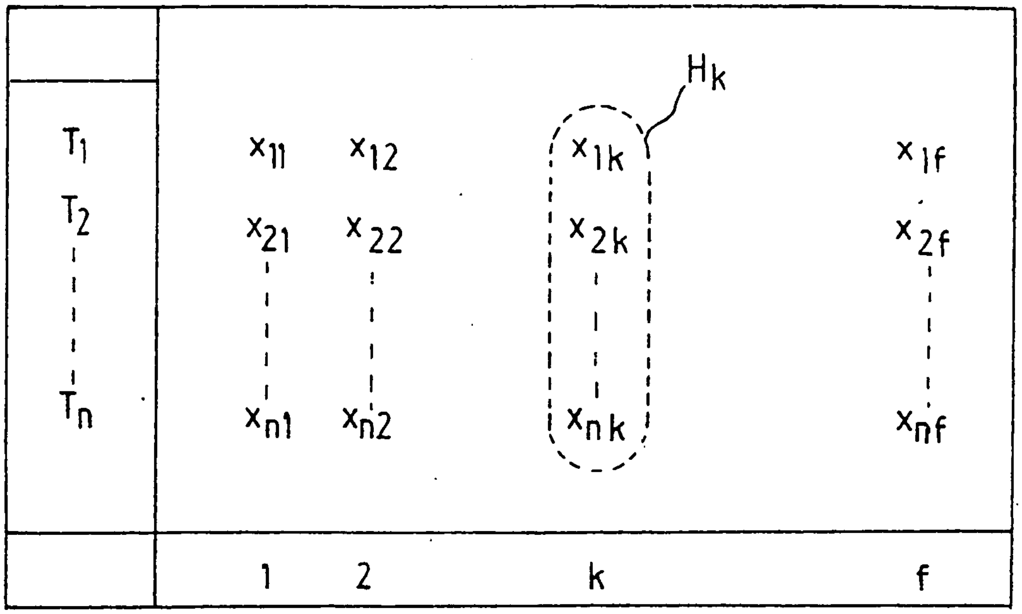

H_k
T_1
T_2
T_n
x_{11} x_{12} x_{1k} x_{1f}
x_{21} x_{22} x_{2k} x_{2f}
x_{n1} x_{n2} x_{nk} x_{nf}
1 2 k f

FIG. 4

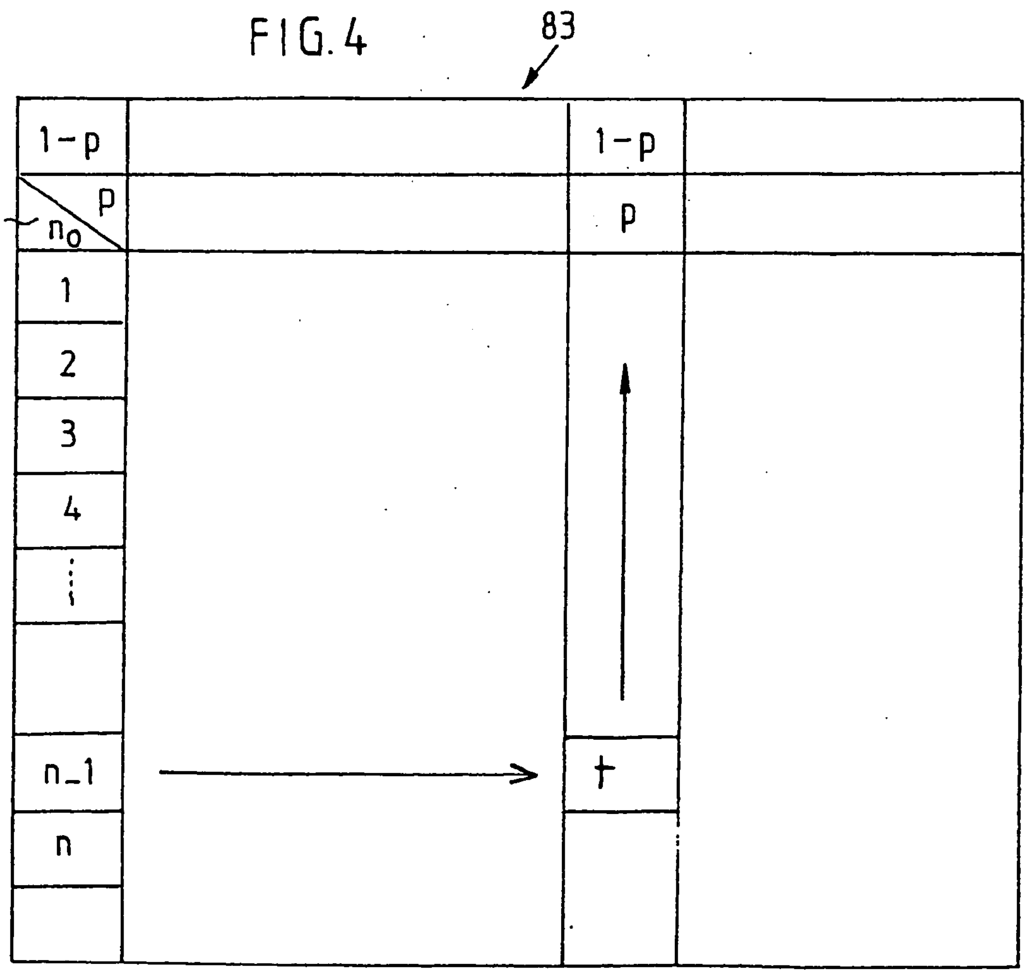
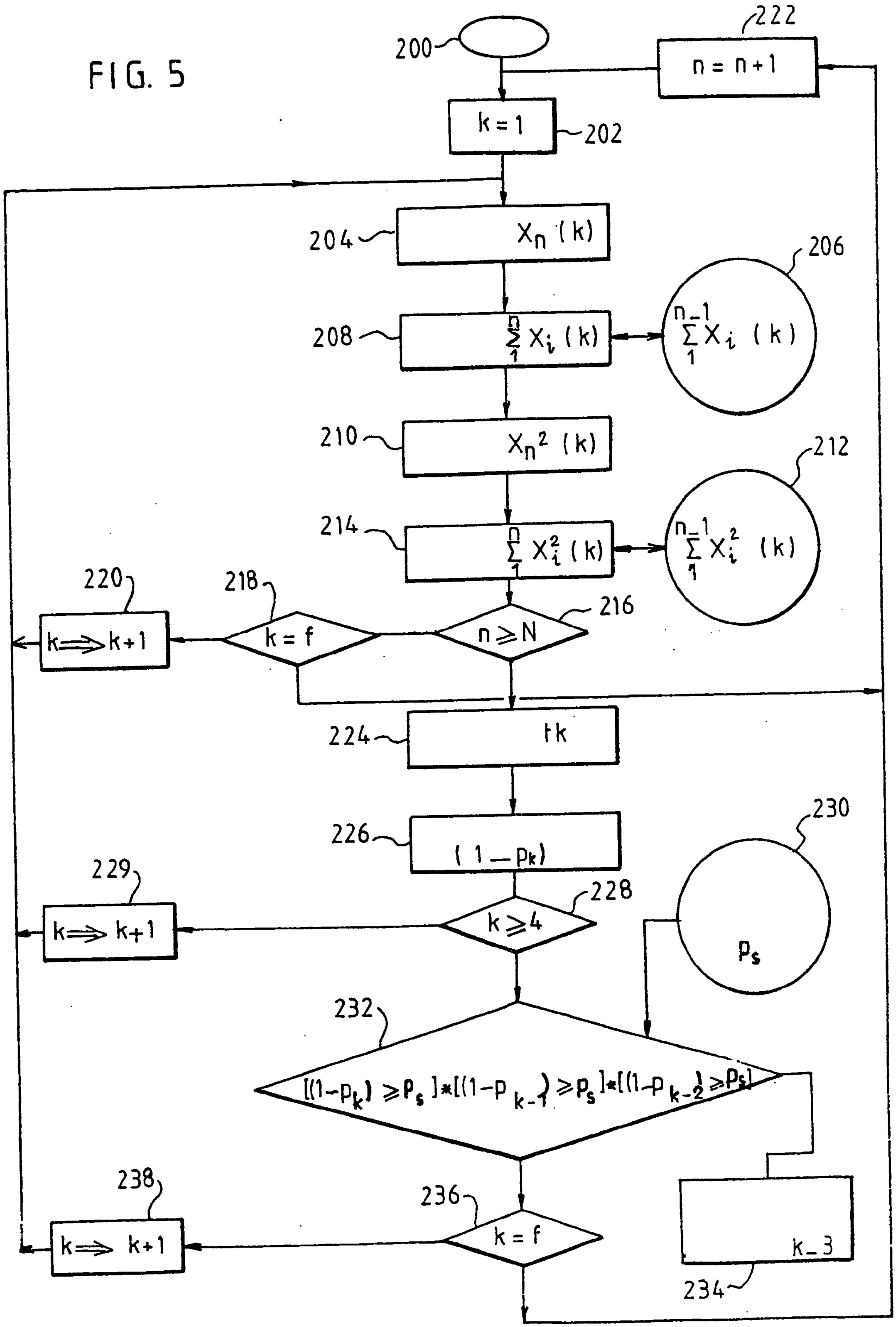

83
1−p
p
n_0
1
2
3
4
n_1
n
1−p
p
+

FIG. 5


200
222
n = n+1
k = 1
202
204
Xn (k)
206
208
$\sum_1^n X_i(k)$
$\sum_1^{n-1} X_i(k)$
210
$X_n^2(k)$
212
214
$\sum_1^n X_i^2(k)$
$\sum_1^{n-1} X_i^2(k)$
220
218
216
k⟹k+1
k = f
n ≥ N
224
tk
226
230
(1 — pk)
229
228
k⟹k+1
k ≥ 4
ps
232
$[(1-p_k) \geq p_s]*[(1-p_{k-1}) \geq p_s]*[(1-p_{k-2}) \geq p_s]$
238
236
k⟹k+1
k = f
k_3
234

SPECIFICATION

Method and apparatus for detecting the instant of arrival of a seismic wave

The invention relates to geophysical exploration of the subsoil, and in particular to seismic prospecting in which a shock is produced at a transmission point, thereby causing seismic waves to propagate through subsurface rock formations. The starting instant of time is recorded, and the propagating waves are picked up at receiver points by devices such as geophones. Information about the structure of the subsoil can then be obtained from the variations in the received signals as a function of time, measured from the instant at which the shock producing the signals was transmitted.

There are several methods of seismic prospecting. Some make use of waves propagating between a transmission point on the surface of the Earth's crust, and a plurality of receiver points which are likewise on the surface. Others use a transmission point that is on the surface of the Earth together with one or more receiving geophones located at depth in boreholes, or *vice versa*.

In all such methods, the signals picked up by each individual geophone correspond to waves which have propagated directly from the transmission point to the receiver point, and also to waves which have followed a path including one or more reflections at the interface between different strata or other discontinuities in the make up of the subsoil.

Since the path followed by the waves that are transmitted directly is shorter than the path of reflected waves, direct waves are always received before reflected waves. It is important to establish accurately the instant of first arrival of a seismic wave at a receiver point in response to a given shock produced at a transmission point. This data is essential for determining, by suitable processing, which portions of the received wave trains correspond to reflected paths, and hence contain information about the stratigraphic structure of the region of subsoil explored. A knowledge of the instants of first arrival of the first arrival of the seismic waves is also useful for determining the transit times of sound waves in the different media through which a hole has been drilled. This knowledge can be used to calibrate the transit times measured directly in a borehole using an acoustic sonde. These transit times are integrated and then correlated with the transit times obtained from the seismic measurements in order to reset the origin of the sonic measurements and to rid them of the influence of borehole conditions, thereby obtaining accurate vertical profiling of the sound wave transmission properties of the formations through which the hole is drilled.

A more complete understanding of these vertical seismic profiling techniques can be obtained from Special Publication No. 12 of the journal Geophysics which appeared in 1973 under the title "Vertical Seismic Profiling" by E.I. Gal'Perin.

If seismic measurements were performed in an ideal medium that was noise-free, the signal received by a geophone after a shock had been produced at a transmission point would be flat until the first arrival of the seismic wave corresponding to the shock. At this instant, the received signal would suddenly begin a series of repeated oscillations. The arrival time of the corresponding seismic wave would then be the instant at which there was a sudden change in the slope of the signal picked-up by the geophone as it departed from a value of zero. On a recording of the signal from the geophone in the form of traces, called "seismic traces", the first arrival point of a seismic wave would then be easy to locate, not only by the human eye, but also by some suitable form of signal processing, since it is essential for the measuring process to be automated. One simple method of doing so would be to determine the average slope of the first portion of the received oscillation and to determine the point of intersection of a straight line of corresponding slope with the line corresponding to a zero value signal. In practice such a technique cannot be used because for various reasons, signals received from geophones are always affected by noise. The zero signal line is not straight, and oscillations corresponding to the reception of a seismic wave are often subject to interference. The methods by which the received traces are processed to detect the existence of a seismic wave arrival, and to determine the instant of arrival, are thus necessarily considerably more complicated.

Further, it is common practice in seismic measurements performed between a point of the surface of the ground and a point within a borehole, to repeat the propagation measurements over successive shocks, in order to be able to stack the traces from a plurality of shock transmissions. The stacking consists of computing average values of the amplitudes of the traces obtained (by the simple processes of point-by-point summing) for each instant following a shock reference instant. This helps to improve the signal-to-noise ratio somewhat, not only for detecting the instant of first arrival, but also for detecting echos from transitions between adjacent strata. In present practice, when some of the traces appear to be excessively affected by noise, they are eliminated by visual inspection before stacking. Thus, these traces are not used in the determination of the first arrival instant of the seismic wave. Further, their information content is completely lost for the processing that locates strata. This means that a relatively high number of individual measurements need to be made to measure the conditions between a transmission point and a receiver point. Each individual measurement requires its own shock to be triggered, and a corresponding trace to be recorded. These operations take time, and the time during which the borehole installations remain idle adds to total prospecting costs.

One aspect of the present invention aims to determine the arrival instant of a seismic wave after the shock that produced it in a manner that is more accurate and more automatic.

This aspect of the invention provides a method of detecting the instant of arrival of a seismic wave

propagating through a subsoil medium between a transmission point and a receiver point, in which successive shocks are transmitted from the transmission point and a signal train is produced representative of the waves received at the receiver point during each of a plurality of observation windows corresponding to respective ones of said shots, a succession of identical instants in each of said observation windows being taken into consideration for each of the different signal trains and the value of the signal at each instant in said succession being recorded for the respective trains, characterised in that a magnitude which is a function of at least one of said values is statistically analysed to determine whether values of said magnitude at each instant under consideration manifests any systematic feature or coherence for the set of recorded signal trains, said analysis being repeated for a plurality of instants in said succession of instants, and the instant of first arrival of the waves at the receiver point being determined as a function of the results of said analyses. The operation is preferably performed for consecutive instants in order of increasing time.

The invention takes advantage of the fact mentioned earlier, that a plurality of signal trains, each corresponding to a respective transmission of shock waves, is recorded from each receiver point to be subsequently combined in order to improve the signal-to-noise ratio, particularly when at least one of the transmission and receiver points is located in a borehole. Instead of determining the instant of first arrival from the stack of said recorded trains, all the information contained in each trace is taken into account when determining said instant of first arrival relative to the instant the shock was transmitted.

In one implementation of the invention, a minimum threshold is fixed in advance for the probability of the distribution of said magnitude at any given instant corresponding to coherence in said train. It can then be decided that said probability threshold being exceeded for one instant, or for a combination of instants such as three in succession, is indicative of the first arrival of the received seismic wave. The instant of wave arrival can then be fixed as a function of the instants in said combination. For example, the instant of first arrival may be chosen as the instant preceding a series of three consecutive instants in increasing time order during which the chosen probability threshold is exceeded.

In a particularly advantageous implementation of the invention, when it is desired to determine the instant of first arrival of the seismic wave in real time, said instant is sought on the basis of some minimum number of traces which are analysed using the above-defined method. If such analysis fails to determine an instant of first arrival with the required probability, the newly acquired trace is added to the previously analysed traces, and the procedure is repeated.

The magnitude whose distribution is analysed may simply be the value of each of the seismic traces at the instant under consideration. It is also possible to use a function of said value and at least one other value in the train. For example, we have been successful using a combination in which the magnitude taken into consideration at each instant is a function of the average slope of the train in the vicinity of the instant under consideration.

Using the method outlined above, it is possible to take advantage from all of the seismic traces, even the noisy ones, recorded for propagation between a given transmission point and a given receiver point. There is no need for prior visual inspection. The method is systematic. It does not make use of techniques which simulate the kind of analyses which a human observer might perform: techniques that run into difficulties when the traces are masked by a relatively high level of noise. Finally, it can be performed quickly.

The invention also provides apparatus for detecting the first arrival of a seismic wave, said apparatus comprising a combination of means which are organised to perform the method outlined above.

Further explanation, and a description of particular implementations of the invention are given below by way of example with reference to the accompanying drawings, in which:

Figure 1 is a diagram showing a borehole seismic prospecting installation;

Figures 2A and *2B* are diagrams of seismic traces for illustrating the way the invention is implemented;

Figure 3 is a table diagrammatically representing a series of seismic traces in the form of samples taken at discrete time intervals;

Figure 4 is an outline of a table for determining a probability for use in the method in accordance with one aspect of the invention; and

Figure 5 is a flow chart outlining the operation of a data processor when seeking a first arrival time in accordance with the invention.

A seismic borehole probe 10 is lowered down a borehole 11 (Figure 1) on the end of a cable 12 which serves to move the probe along the borehole and to connect it electrically to a mobile laboratory 14 on the surface. The cable passes over a sheave 15 at the top of a drilling rig 16 and drives a pulley wheel 18 tangentially in such a manner that the number of pulley wheel revolutions is proportional to the depth of the sonde 10. In the position shown, a geophone 20 has a sensitive face located in or close to the outside wall of the tool 10. This face is pressed against the inside wall 21 of the borehole 11 by means of two anchoring members 22 which are fixed to the tool 10 and which press against the opposite face 23 of the borehole.

A source of seismic signals 30 is located in a water-filled trench 33 in the surface of the ground at a suitable distance from the borehole 11. The source is, in theory, shaped so as to produce a high powered shock of short duration in the ground, and may be of any well known form, eg. an air gun.

The source 30 is controlled from the laboratory 14. A hydrophone 34 placed close to the source 30 detects the instant at which the wave departs into the ground. This instant serves as a reference point for each shot, i.e. the traces picked up by the geophone 20 are all timed from the moment the corresponding shock produced by the source began to propagate.

Seismic waves propagating between the source 30 and the geophone 20 can follow multiple paths. The direct path is referenced 35. A path with two reflections, one at a stratum 36 and another at the surface 32 of the ground is referenced 37. It results in a wave that is travelling downwards when it reaches the geophone 20. A third path 38 has a single reflection at a stratum 39, and results in a wave travelling upwardly when it reaches the geophone 20.

Because the paths 35, 37 and 38 are of different lengths, the electric signals transmitted by the geophone to the laboratory 14 are shifted in time relative to the initial pulse. Traces 40, 41, 42, 43, and 44 in Figure 2A are records of the amplitudes of the oscillations picked up by the geophone 20 during five successive shots from the source 30, plotted as a function of time TT measured from the initial reference instants which are off to the left of the diagram. The pauses between successive shots are long enough to ensure that each recorded trace corresponds to substantially all seismic propagation paths capable of supplying measurable data.

The left hand point portion 50 of the trace 44 is practically flat and parallel with the time axis up to a point 51 corresponding to an instant TT_1 where the signal is deflected downwards (trough 52) before climbing to a peak 53 at a greater amplitude than the level 50. The set of curves 40 to 44 are manifestly similar to one another to the right of the instant TT_1. The similarities between the curves are representative of the existence of systematic features or coherence in the propagation of seismic waves between the transmission point and the receiver point regardless of the shot that produced the waves. This coherence between the traces is manifest, *inter alia*, from the way the points of first arrival at the instants TT_1 can be seen by eye to be in alignment. However, it should be observed in the case of curve 40 whose left portion is degraded by noise, that it is not easy to locate the exact instant of first arrival by eye or by any method that is functionally similar to the human eye and brain.

The signals picked up for each trace (via input 63) are acquired and digitised under the control of a control and processing unit 64 in the laboratory 14. The control and processing unit 64 receives depth data in the form of pulses from the pulley 18 via a link 65. Unit 64 is connected to the source 30 and to the hydrophone 34 via respective conductors 62 and 66. A magnetic recording unit 67 stores digitized data corresponding to each recorded trace.

Let there be *n* traces T_1 to T_n acquired under the control of the device 64 from a sequence of *n* shots (Figure 3). The amplitude of each trace is represented by digital values $x_i(k)$ obtained by sampling over regular time intervals at instants *k*, where *k* lies in the range 1 to *f*. For each trace the instants 1 to *f* are determined from an origin constituted by the instant at which the corresponding shot, was generated. Values having the same index *k*, such as $x_1(k)$, $x_2(k)$, ... $x_n(k)$, correspond, to the same transit times for the seismic wave between the source 30 and the receiver point or geophone 20. Nonetheless, these values are not identical because of the noise to which the signals are subject.

Signals picked up at instants *k* prior to the instant of first arrival of waves at the geophone 20 can only correspond to noise $N_i(k)$ for each trace *i*. On the basis of this observation, each group of values concerning a particular instant *k*, (for *k* in the range 1 to *f*), can itself be considered as constituting a sample H_k taken from a set of numbers that obey different laws of statistical distribution depending on whether the sampling instant *k* is before or after the instant of first arrival.

Supposing that the noise is Gaussian, the mathematical expectation associated with each sample H_k prior to the first arrival instant must be zero. In contrast, the expectation must be non-zero for the instants which immediately follow the first arrival.

Since the number of recorded traces may be relatively small, the distribution of each sample H_k corresponding to an instant *k* is supposed to obey Student and Fisher's law.

Student's t-variable is calculated for each sample of order *k* using the equation:

$$(1) \qquad t_k^2 = \frac{\sum_{i}^{n} X_i(k)^2 (n-1)^2}{n\left[n\sum_{i}^{n} X_i(k)^2 - \left(\sum_{i}^{n} X_i(k)\right)^2 \right]}$$

in which $X_i(k)$ is a function of the value $x_i(k)$ and possibly other values, as is explained further on.

According to Fischer's law, the variable t_k has a probability distribution given by the equation:

$$(2) \qquad p(tk) = \frac{1 \quad \Gamma((n_o+1)/2)}{\sqrt{2\pi}\,\Gamma(n_o/2)(1+t^2/n_o)((n_o+1)/2)}$$

in which the function Γ obeys the relationship $\Gamma(n+1) = n\Gamma(n)$ and n_o is the number of degrees of freedom.

When there are n independent seismic traces, the number of degrees of freedom, or number of draws or samples that can be drawn from a set of Gaussian distribution, is $(n-1)$.

As n increases, the distribution of the variable t_k gets closer to a normal or Gaussian distribution corresponding to the distribution of the set from which the draws are taken. When the number of items in each sample under consideration (ie. the number of traces) exceeds 30, the t distribution approximates very closely the normal distribution.

For smaller numbers of traces, the value of the probability $p(t_k)$ may be taken from a Student and Fischer table, instead of being calculated from equation (2). It is then possible to obtain directly or by extrapolating the probability p_k of the set from which the sample was taken having an average value of zero (only noise present) and the probability $(1-p_k)$ of the average value being other than zero, ie. of the set from which the sample was taken corresponding to a superposition of noise and signal which has a similar or coherent effect in each of the traces.

Figure 4 outlines a table 83 of values of the variable t which may be stored in a memory of the apparatus 68 for detecting the instant of first arrival. The table has two sets of indices for defining rows and columns respectively. Each row corresponds to a particular number of degrees of freedom n_o. Each colum corresponds to a given probability p that a sample is taken from a set having an average value of zero, or to the probability $(1-p)$ that the reciprocal condition is true.

Thus, given a set of traces T_1 to T_n, which have been amplitude-sampled at discrete instants k in the range 1 to f (Figure 3), Student's t-variable t_k may be calculated for each instant k. The table of Figure 4 provides, for the number of degrees of freedom $n-1$ and the value t_k in that row, the corresponding probability $(1-p_k)$ that the sample H_k constituting values $X_1(k)$ to $X_n(k)$ was taken from a set having a non-zero average value and thus indicates the presence of a useful signal.

Consequently, the samples H_k may be examined in order of increasing time until the probability $(1-p_k)$ exceeds a predetermined threshold, eg. 0.99. To make the operation more certain, it may be decided, as in this example, that the presence of a coherence signifies the existence of a useful signal only after three consecutive samples H_k in time increasing order have all given a probability $(1-p_k)$ which exceeds said threshold.

The instant of first arrival is then defined as the instant immediately preceding the three consecutive samples which satisfied the required condition.

Curve 80 in Figure 2A shows the value of the probability $(1-p)$ obtained using the above method on the five traces 40 to 44. By reading the curve 80 from left to right, it can be observed that the instant of first arrival TT_1 is the first instant after which the probability $(1-p)$ is stable at its maximum value for several consecutive instants of time TT.

In practice, the sample H_k may comprise variables which, although dependent on the instant k under consideration in the trace detection interval, are not necessarily the values or the amplitudes of the traces at said instant k.

Thus, in general terms, the sample H_k comprises the values of a variable $X_i(k)$ derived from each trace T_i. For example, instead of using the amplitude $x_i(k)$ of the trace T_i as the value for $X_i(k)$, the difference between two consecutively sampled values of the trace could be used, ie. $x_i(k) - x_i(k-1)$. It has also been observed that good results can be obtained by letting $X_i(k)$ have the value of the gradient of the least squares fit line through five consecutive samples from the instant k, ie. through samples $x_i(k)$ to equation has been used:

$$X_i(k) = \frac{1}{10}\left[-2x_i(k) - x_i(k+1) + x_i(k+3) + 2x_i(k+4)\right] \tag{3}$$

The variable derived from equation (3) has the advantage of eliminating any DC component that may be present in the seismic traces.

Figure 2B shows traces 140, 141, 142, 143 and 144 which have the same information content concerning seismic propagation between the points 30 and 20 as the traces 40 to 44 in Figure 2A, but each of the traces in Figure 2B has had additional Gaussian noise added thereto.

A curve 81 shows the resulting values of the probability $(1-p)$ obtained using the method in accordance with the invention. It should be observed that the curve 81 still enables the point TT_1 to be accurately determined, even though determining its position from any one of the traces 140 to 144 has been made difficult, if not impossible.

Figure 5 summarises the operation of the control unit 64 shown in Figure 1 for detecting the first arrival time as the seismic traces are being acquired for waves propagating between a transmission point 30 and a receiver point 20. It is assumed that the search for the instant of first arrival is commenced once some minimum number of traces, eg. 5, has been recorded.

After initialisation (block 200), a counter for counting the time instants k is set to unity and the value of the variable X is calculated for the trace n currently being acquired, ie. $X_n(k)$, see block 204. The value

$$\sum_{1}^{n-1} X_i(k)$$

is taken from a memory 206 which is used for storing the sum of the values of the variable X at instant *k* as calculated for all the traces obtained so far. The stored sum is added to the newly calculated value from block 204 to obtain (block 208) a new sum value

$$\sum_{1}^{n} X_i(k).$$

The value $X_n^2(k)$ is then calculated in block 210. Then the sum of said squares

$$\sum_{1}^{n-1} X_i^2(k)$$

as calculated so far is taken from a register 212 and a new sum

$$\sum_{1}^{n} X_i^2(k)$$

is calculated in a block 214 from the new value provided by block 210.

A check is then made to see whether the number of traces acquired so far is greater than the minimum N required for investigating the distribution (block 216). If not, eg. if *n* is less than 5, a check is made to see if all the instants *k* of an observation window have been dealt with (block 220), and the system returns to block 204 to repeat the procedure outlined above. This is continued with all *f* instants in the interval have been dealt with.

When this happens, (k=f in block 218), the number of the trace is incremented (n=n+1, see block 222) and the next trace is acquired by returning to block 202.

When the number of traces already acquired is greater than or equal to the minimum N (answer YES in block 216), Student's variable (t_k) is calculated in block 224 in the manner already described.

The corresponding probability $(1-p_k)$ is then looked up in the Student-Fisher table (block 226) described with reference to Figure 4. Naturally, the value of $(1-p_k)$ may be interpolated should the calculated value of t_k turn out to fall between two adjacent stored values in the row corresponding to n−1 degrees of freedom.

A check is then made to see whether *k* is greater than or equal to 4 (block 228), and if not, *k* is incremented by unity and the system returns to block 204.

Otherwise, a test is performed to see whether the probabilities obtained for instants k, k−1, and k−2 are all above a threshold probability p_s which is predetermined and stored in an external register 230, eg. having a value of 99%. If this condition is satisfied, (answer YES to block 232), that means that the signal corresponding to the first seismic wave arrival has been found by reading through all *n* traces together in order of increasing time. The instant of first arrival is then taken to be k−3 as indicated in block 234.

In the event that the condition tested in block 232 gives the answer "NO", a test is made to see whether the entire measurement window for the trace *n* has been examined (block 236). If not, *k* is incremented by unity (block 238) and the system returns to block 204. Otherwise, if all the samples from trace *n* have been examined without it being possible to determine the instant of first arrival, the system moves on to the acquisition or reading of the next trace and returns via block 222 to block 202, and the process is repeated.

Once enough traces *n* have been obtained for finding the first arrival time with sufficient accuracy, and the arrival time has actually been determined (block 234), the process is terminated.

The above operations can be implemented with the automatic processing equipment usually to be found in mobile logging units. The only specific requirements are two buffer registers (blocks 206 and 212) for the sums and a three position memory for the values $(1-p_k)$.

Instead of doing such processing in real time, the processing can be done in deferred time, provided a plurality N_m of previously recorded traces is available and stored in the magnetic memory 67. The number N_m must be much greater than the minimum number N. The operations outlined in the set of blocks 204 to 226 is then performed for each instant *k* in increasing time order until three values are found which satisfy the condition in block 232.

CLAIMS

1. A method of detecting the instant of arrival of a seismic wave propagating through a subsoil medium between a transmission point and a receiver point, in particular where at least one of said points is located underground, and in which successive shots are transmitted from the transmission point and a signal train (i) is produced representative of the waves received at the receiver point during each of a plurality of observation windows corresponding to respective ones of said shots, a succession of instants (k) counting from a reference instant in each of said observation windows being taken into consideration, said succession being identical for all the trains, and with the value $x_i(k)$ of each signal train at each instant (k) being recorded, for the respective train, wherein a magnitude $X_i(k)$ which is a function of at least one of said values $x_i(k)$ is statistically analysed to determine whether the distribution of the samples (H_k) constituted by the values of said magnitude which correspond to an instant *k* manifests any systematic feature or coherence of the set of trains received, said analysis being repeated for a plurality of successive instants *k*, and the instant of first arrival of the waves at the receiver point being determined as a function of the results of said analysis.

2. A method according to claim 1, characterised in that the statistical analysis operation is repeated for said successive instants in the order of increasing time and said instant of first arrival is determined as a function of at least successive instants.

3. A method according to claim 1 or 2, characterised in that a minimum probability threshold (p_s) is fixed above which said distribution of the sample (H_k) at an instant *k* is considered to correspond to the pressure of coherence.

4. A method according to claim 3, characterised in that the received signals are considered to correspond to the first arrival of the seismic wave once said coherence has been detected for a predetermined combination of a plurality of successive instants (k−2, k−1, k).

5. A method according to 4, characterised in that the instant of first arrival is taken to be at a predetermined instant (k−3) preceding said combination of instants.

6. A method according to any preceding claim, characterised in that the instant of first arrival of the seismic wave is sought on the basis of a minimum number of trains which are analysed at instants in order of increasing time in the observation window, and, in the event of an unsuccessful search, in that the search is repeated by adding at least one newly acquired train to the set of trains under consideration.

7. A method according to any preceding claim, characterised in that the presence of coherence in the signal trains (T_1 to T_n) is determined by means of the Student-Fisher test.

8. A method according to any preceding claim, characterised in that the magnitude $X_i(k)$ taken into consideration at each instant (k) is a function of the value $x_i(k)$ of the signal in each train at said instant and of at least one other value of the signal in said train.

9. A method according to any preceding claim, characterised in that the magnitude $X_i(k)$ taken into consideration at each instant (k) is a function of a feature associated with the slope or the average slope of the signal in each train (i) in the neighborhood of the instant under consideration (k).

10. Apparatus for detecting the instant of arrival of a seismic wave propagating through a subsoil medium from a transmission point to a receiver point, the apparatus being of the type that includes means for acquiring picked-up during an observation window following the transmission of a shock, and means for recording said acquired signals in the form of traces of a plurality of successive shocks, characterised in that the apparatus further includes means for examining the distribution (H_k) of a magnitude obtained from the set of recorded traces at each instant in the observation window, means for determining the probability that the distribution of said set of traces manifests the existence of coherence in the set of recorded traces at the corresponding instant, and means for detecting when said probability exceeds a predetermined threshold.

11. Apparatus according to claim 10, characterised in that it further includes a register for summing the values of said magnitude, and a register for summing the squares of the values of said magnitude, and a memory for storing a probability distribution table for a Student-Fisher variable.

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